AD-A051 148 BENDIX CORP BALTIMORE MD COMMUNICATIONS DIV F/G 17/7
DESIGN, FABRICATION, AND TESTING OF BRASSBOARD MODEL ATCRBS BAS--ETC(U)
DEC 77 A L BROCKWAY, J B KUHL, P J WOODALL DOT-TSC-769
UNCLASSIFIED BENDIX-489A10A FAA-RD-77-174 NL

| OF |
AD
A051148

END
DATE
FILMED
4-78
DDC

REPORT NO. FAA-RD-77-174

12

DESIGN, FABRICATION, AND TESTING OF BRASSBOARD MODEL ATCRBS BASED SURFACE TRILATERATION DATA ACQUISITION SUBSYSTEM

A. L. Brockway
J.B. Kuhl
P.J. Woodall

Bendix Corporation
Communications Division
East Joppa Road
Baltimore MD 21204

DECEMBER 1977

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research and Development Service
Washington DC 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

(18) FAA-RD, TSC

(19) 77-174, FAA-77-26

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-77-174		(11)

4. Title and Subtitle
(6) DESIGN, FABRICATION, AND TESTING OF BRASSBOARD MODEL ATCRBS BASED SURFACE TRILATERATION DATA ACQUISITION SUBSYSTEM.

5. Report Date
December 1977

6. Performing Organization Code

7. Author(s)
(10) A. L. Brockway, J.B. Kuhl and P. J. Woodall

8. Performing Organization Report No.
DOT-TSC-FAA-77-26
(14) Bendix-489A10A

9. Performing Organization Name and Address
Bendix Corporation*
Communications Division
East Joppa Road
Baltimore MD 21204

(12) 40p.

10. Work Unit No. (TRAIS)
FA721/R8113

11. Contract or Grant No.
(15) DOT-TSC-769

13. Type of Report and Period Covered
(9) Final Report,
June [illegible]-Dec 1975

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Aviation Administration
Systems Research and Development Service
Washington DC 20590

14. Sponsoring Agency Code

15. Supplementary Notes
*Under Contract to: U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

16. Abstract

Field-test results are emphasized in this report which also contains background information on airport surface traffic control (ASTC) and the contract objectives. The field-test series proved the technical feasibility of an air traffic control radar beacon system (ATCRBS) based ASTC sensor system.

Operational data acquisition subsystem (DAS) performance projections developed to date as a result of the test series are presented, and a recommendation for pursuit of further testing is substantiated.

17. Key Words	18. Distribution Statement
Airport Surface Traffic Control (ASTC) Air Traffic Control Radar Beacon System (ATCRBS) Data-Acquisition Subsystem (DAS) Transponder Surveillance	DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	40	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

402 895

JB

PREFACE

The U.S. Department of Transportation tasked the Transportation Systems Center (TSC) with development of airport surface traffic control (ASTC) systems required to meet the present and future needs of the FAA and airport users. The primary objective of Contract DOT-TSC-769 is to establish the feasibility of an ATCRBS based trilateration data-acquisition subsystem for airport surface traffic surveillance. This summary final report covers Task 2B of that contract, i.e., fabrication and field testing of the ASTC brassboard equipment at NAFEC.

Analysis[1/2] indicated that a system using a spatial combination of ATCRBS sidelobe suppressions and interrogations will satisfy all major ASTC sensor requirements in the FAA's Upgraded Third-Generation ATC system. The GEOSCAN® (for Geographic Scanning) technique developed by Bendix forms the basis for such a system. Using GEOSCAN, discrete aircraft on an airport surface can be selectively interrogated. ATCRBS transponder replies from addressed aircraft can then be processed to locate and identify the target. The trilateration process (i.e., measuring time of arrival of the reply at three or more stations) can be used to provide data to compute aircraft location, while aircraft identity can be obtained by decoding pulses in the reply signal train.

The NAFEC test series from August through November 1975, demonstrated that GEOSCAN works, and proved the technical feasibility of the ATCRBS based surface trilateration concept. Compatibility of this system with ATCRBS/ARTS III and NAS Stage A systems was investigated during the NAFEC test series, and results show that ATC operational system performance will not be degraded by the implementation of ATCRBS based ASTC systems.

Although the NAFEC tests were successful and most encouraging, the scope of the tests was limited due to the NAFEC environment. It seems clear that testing of the Brassboard system at a relatively high traffic density operational airport (Logan, Boston) is

necessary and should be undertaken.

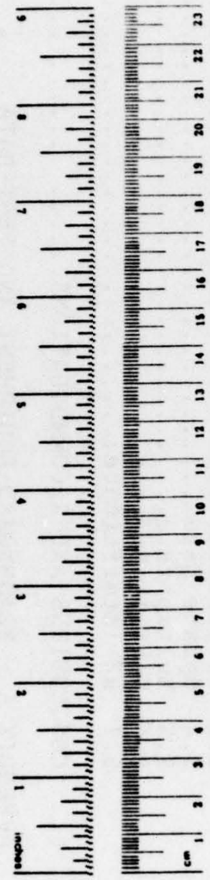
This contract was administered by the TSC Airport Systems Branch under John W. O'Grady, and was conducted by the ATC Engineering Department of the Bendix Communications Division.

Many people at TSC (Cambridge), FAA/NAFEC, and Bendix contributed to the successful completion of the NAFEC test program. In particular, the authors wish to thank M. J. Moroney of TSC for his direction and support throughout the program. Also, the contributions and helpful comments of J. L. McCormick (Bendix), J. D. Vinatieri (MITRE, Bedford), R. D. Kodis (TSC), Harry Jackson (FAA/NAFEC), and S. Ross (S. Ross & Co.) are sincerely appreciated.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

This report covers work performed by the Bendix Communications Division (BCD) through January 1976 under Contract DOT-TSC-769 for the design, fabrication, and field testing of a brassboard model ATCRBS based trilateration data acquisition subsystem (DAS) for Airport Surface Traffic Control (ASTC). This work is an integral part of the ongoing ASTC program being conducted for the U. S. Department of Transportation (DOT), Federal Aviation Administration (FAA), by the Transportation Systems Center (TSC). To establish the technical feasibility of a surveillance technique for ASTC based on the air traffic control radar beacon system (ATCRBS), a brassboard model of a data acquisition subsystem (DAS) was designed and built by Bendix. This brassboard system contains the equipment necessary to selectively interrogate, detect, and record the position and identity of vehicles on the airport surface. This is accomplished by use of the GEOSCAN® (acronym for geographic scanning) interrogation technique and by means of time-of-arrival (TOA) measurements made at three sites on ATCRBS transponder replies from target vehicles. The DAS was field-tested at NAFEC to verify the <u>feasibility</u> and <u>performance capability</u> predicted by theoretical analysis.

This report contains results of the NAFEC field tests along with a digest of data previously reported[1,2,3] by Concept Analysis Task 1A, and DAS Hardware Design Task 2A.

2. BACKGROUND

ASTC is one of the nine major programs in the FAA's upgraded third-generation ATC system (UG3RD) aimed at improving performance, safety, and cost. The UG3RD will provide for all-weather surveillance, guidance, and control of increased numbers of aircraft to meet the needs of the 1980's and 1990's. The National Aviation System Plan for Fiscal Years 1976-1985 calls for "establishing modern airport suface guidance and air traffic detection and control aids."[4] As the technology arm of DOT, TSC was given responsibility for undertaking the ASTC R&D program under the Airport Safety and Facilities Support Branch (ARD-420), Airport Division, Systems Research and Development Service (SRDS) of the FAA.

Contract DOT-TSC-769, awarded to the Bendix Communications Division by the TSC, called for the "design, fabrication, and testing of a brassboard model ATCRBS based surface trilateration data-acquisition subsystem" which, if feasible, would be used as the sensor input in the advanced surface surveillance system.

The major problem arising from the use on the airport surface of existing ATCRBS transponders is the mutual interference caused by overlapping transponder replies. A solution was invented by Bendix using a method of discrete transponder interrogation that takes advantage of existing attributes of the ATCRBS system. This new concept, GEOSCAN,® is essentially a form of bistatic interrogation tailored to provide time/space addressability. This system can elicit a reply from one surface aircraft at a time. Aircraft position can then be determined using trilateration techniques. Identity (ID) also can be obtained from the reply.

3. PROGRAM OBJECTIVES

The major objective of this program was to evaluate the feasibility and operational potential of an ATCRBS based surface trilateration DAS through the design, fabrication, and testing of a brassboard model.

The beacon based systems program is one of several programs underway at TSC aimed at developing technology to support an integrated ASTC system. The fabrication and testing of the brassboard system was considered a key effort because the identity of aircraft is required, and the equipment must function in the airport environment with the existing ATCRBS.

Given the constraints of operating in the airport environment and meeting the operational requirements stipulated, the aims of this contract can be stated as:

a. To measure how well the DAS performed;

b. To evaluate the compatibility of the DAS with other ATC functions;

c. To ascertain the effects of multipath, fruit, and other interference on DAS performance; and

d. To determine the extent to which line-of-sight interference degraded DAS performance.

The DAS was not configured in an operational form, so that the evaluation of its operational potential was based on analytical studies as validated by empirical data obtained by field testing. The data base established from field test results was used in developing preliminary performance characteristics for an operational ASTC DAS.

The basic contract was organized into three tasks: concept analysis, hardware development, and a NAFEC field-testing program. Three optional tasks were also included for the purpose of gathering additional test data at operational airports. This program proceeded in parallel with a TSC ASTC system study defining the requirements of a complete surface surveillance system.[5] The brassboard equipment was simplified as much as possible to minimize

costs and development time. It resembles an operational DAS only with respect to the basic RF processes of interrogation and reception. A description of DAS operation is given in Appendix A of the final report. Appendix B gives performance characteristics for the brassboard DAS.

4. OVERVIEW OF ACCOMPLISHMENTS

This program was initiated in June 1974. The concept analysis study was started at that time. There were seven critical technical issues on which the feasibility of the concept depends:

- ACCURACY
- SURFACE COVERAGE
- RESOLUTION
- UPDATE RATE
- MULTIPATH
- VEHICLE EFFECTS
- RF INTERFERENCE

The brassboard system consists of three transportable stations together with additional test equipment and instrumentation used to calibrate test vehicles. Two of the stations contain an interrogator and a null-steering phased-array antenna. The third station contains a TOA receiver to complete the three-station trilateration network. The three stations are interconnected by microwave links for the transmission of timing and steering data, and the transfer of test data to a single recorder at the Master Station. A voice-communications network was established for test control and direction purposes.

The Master Station has a Test Control Unit (TCU) which controls the sequencing and timing of interrogations, reply reception, and antenna scanning. This unit is manually programmed to conduct each test. Steering and interrogation commands are supplied in real time to the remote, or slave interrogator station via the microwave link. Three TOA counters and decoders are present in the Master Station to measure signals from each receiver. These data are recorded in digital form on a high-speed magnetic tape recorder along with DAS steering information and interrogation timing data. TOA and data can also be read out on a display in the Master Station. The tapes recorded during each test were

supplemented by test engineer observations (engineer's log). Processing of tapes was accomplished off-line at TSC using software programs developed under this contract.

Physically, each station consists of a trailer with an ATC power generator, heating, air conditioning, an antenna support tower, a DAS antenna, a microwave data link, communications antennas as required, and a DAS electronics equipment rack containing equipment required at that station. The system is transportable and requires neither permanent (e.g., concrete pads) site preparation nor electrical-mechanical interfaces with other airport facilities.

The brassboard was required to be tested at NAFEC in Atlantic City, NJ. Also included were the test planning, test analysis, data processing, and software development. To meet the program schedule, the planning and software development work were conducted while the hardware was being fabricated.

Installation of the brassboard at NAFEC was begun in August 1975, and the system was operational in accordance with the test plan. The field-test program was designed to gather test data in each of the identified key technical areas. Tests were performed first using fixed targets, then single-moving targets, and finally multiple targets. Test vans instrumented with beacon transponders were used in early test. Later in the series, FAA aircraft were employed.

Five ATCRBS interference evaluation tests were conducted at NAFEC to assess the compatibility of the DAS with the existing ATCRBS environment. The DAS was synchronized to operate in the dead time of the NAFEC ASR-4 (airport surveillance radar; as it would be in an operational system) to preclude interference with this operational site. During the first interference evaluation test, the DAS PRF (pulse repetition frequency) was set equal to the ASR-4's (approximately 380 per second), and the DAS was periodically turned on and off as the DAS power output was increased from minimum to maximum. Observers were stationed at the Philadelphia and Washington-National TRACONS (tower radar control), and at the

4. OVERVIEW OF ACCOMPLISHMENTS

This program was initiated in June 1974. The concept analysis study was started at that time. There were seven critical technical issues on which the feasibility of the concept depends:

- ACCURACY
- SURFACE COVERAGE
- RESOLUTION
- UPDATE RATE
- MULTIPATH
- VEHICLE EFFECTS
- RF INTERFERENCE

The brassboard system consists of three transportable stations together with additional test equipment and instrumentation used to calibrate test vehicles. Two of the stations contain an interrogator and a null-steering phased-array antenna. The third station contains a TOA receiver to complete the three-station trilateration network. The three stations are interconnected by microwave links for the transmission of timing and steering data, and the transfer of test data to a single recorder at the Master Station. A voice-communications network was established for test control and direction purposes.

The Master Station has a Test Control Unit (TCU) which controls the sequencing and timing of interrogations, reply reception, and antenna scanning. This unit is manually programmed to conduct each test. Steering and interrogation commands are supplied in real time to the remote, or slave interrogator station via the microwave link. Three TOA counters and decoders are present in the Master Station to measure signals from each receiver. These data are recorded in digital form on a high-speed magnetic tape recorder along with DAS steering information and interrogation timing data. TOA and data can also be read out on a display in the Master Station. The tapes recorded during each test were

Islip-New York and Leesburg-Virginia, ARTCC's (air route traffic control center) to record any sign of interference with ATC operations. These observers also obtained ARTS III data-extraction tapes and printouts to evaluate quantitatively effects of the DAS on ATCRBS performance. Controller comments during the tests also were collected. The last interference evaluation was performed in November, 1975 between 1800 and 2400 hours at DAS PRF's of 380, 760 and 1520 per second. These data were taken to magnify any effect the DAS might have on the ATCRBS environment. The highest PRF exceeds expected requirements of an operational DAS.

Forty-eight DAS tests were planned, and 42 were completed prior to the conclusion of the NAFEC series in November 1975. Each test usually required a four-hour period with one and sometimes two tests being conducted each day. Test scheduling was planned so that, when possible, the ASTC Program would not conflict with other on-going NAFEC test activities, e.g. MLS (microwave landing system), ILS (instrument landing system), BCAS(beacon collision avoidance system), etc.

Bendix provided personnel to operate and maintain the brassboard equipment and to perform DAS data processing and analysis. The test team which scheduled, coordinated, and performed the brassboard tests at NAFEC consisted of TSC, NAFEC, and Bendix personnel and various subcontractors. This team was augmented by controllers at terminal and en-route sites during the conduct of interference tests.

The GEOSCAN® interrogation sequence was performed in a preprogrammed manner, and reply data was recorded for post-test analysis. The reply data were processed off-line to generate discrete target reports for each interrogation-reply round containing target-position measurements and decoded ID. Expected operational performance was predicted from specific test data and from extrapolated statistical data developed from the tests.

A wealth of test data were obtained during the NAFEC field tests to evaluate the seven key technical issues. A good per-

centage of these data was redundant, providing a data base for comparing similar performance characteristics under varying conditions. These data were analyzed to answer questions concerning concept feasibility and system performance, and a synopsis of the results is presented here.

5. SUMMARY OF RESULTS

Results of the field test program show that the basic ATCRBS trilateration approach is feasible. In the seven key technical areas of investigation, the NAFEC test results were within acceptable tolerance limits of the analytically predicted values. There was never an indication that the DAS as a whole, or any of its functional subsystems, had basic shortcomings or performance limitations which would jeopardize an operational implementation.

While the results are very positive, they should not be misconstrued as a demonstration of a prototype operational DAS since the basic brassboard system was only a test tool used to evaluate feasibility as defined by the key issues.

5.1 ACCURACY

Position-location accuracy obtained within the triangle formed by the three stations is as shown in Table 1. This table was generated from measurements made at 26 discrete surface points supplemented by more than 1000 samples acquired during moving-target tests.

TABLE 1. POSITION-LOCATION ACCURACY

Test Date	Jitter[c] (1σ) ft.	Bias Error[d] (RMS) ft.	Total Error (1σ) ft.
NAFWX (Raw)[a]	6.5	39.1	39.6
NAFEC (Corrected)[b]	6.5	10.8	12.6

[a] As recorded without applying calibration corrections.

[b] Known bias errors removed using calibration correction.

[c] Sample-to-sample error measured at one point in the coverage region.

[d] Difference between the mean measured position and the true position, averaged over the coverage region.

Factors contributing to the bias error include long-term variations in: received signal strength, time delay in the data links, geometric dilution of precision (GDOP), multipath, and clock-count quantization. It can be noted that the NAFEC 1σ accuracy measurement of 12.6 feet is in good agreement with the predicted value of 7 feet, and the 3σ position accuracy of 37.8 feet compares favorably with the contract design objective of 100 feet.

5.2 SURFACE COVERAGE

The surface coverage of an ASTC DAS must be sufficient to elicit replies from any point of interest on the airport surface. To generate accurate position estimates from the replies received at the three trilateration stations, the location of these stations at NAFEC was established so that 87 of all runways/taxiways was within the triangle formed by the station locations. Continuous coverage - up to 1.5 nautical miles for test vehicles and 1.3 nautical miles for aircraft (limited by the runway layout) - was provided within this region. Moving-target test data showed that line-of sight blockage, caused by navigational aid structures, did not prevent this continuous coverage. To meet the nominal reply criteria of the U.S. National Standard, a transponder should reply at least 90% of the time when the received interrogation signal strength at the transponder's antenna is -71 dBm. Surface coverage of an ASTC DAS is achieved wherever the vector sum of the direct-path and the reflected path (vertical multipath) signals exceeds this value. Table 2 indicates the transmitted peak power required to achieve this condition.

The test results indicate that coverage requirements for a range of 2 nautical miles can reasonably be predicted for an operational DAS with the additional gain provided by an operational antenna. It appears, furthermore, that line-of-sight blockage and airport configuration limitations will be greater influences, in determining the location and number of DAS sites required for coverage of an airport, than the range limitations of the DAS equipment.

TABLE 2. POWER REQUIRED TO ACHIEVE COVERAGE

System	Power[a] (Watts)	Aircraft-Antenna Heights (Feet)	Range (Nautical Miles)
NAFEC Data Point (Measured)	31.6	3	1.13
NAFEC Data Point[b] (Calculated)	29.1	3	1.13
Operational[b,c] (Calculated)	44.8	4	2.0

[a]Peak effective radiated power.

[b]Assuming an aircraft-antenna gain of 0 dB and a shadowing loss of -10 dB.

[c]The projected operational antenna has a larger horizontal aperture and vertical directivity, giving an increase in antenna gain on the order of 10 dB.

5.3 RESOLUTION

The resolution of an ASTC DAS is defined as its ability to elicit from a target of interest a reply that is not garbled by an interfering reply from another aircraft in close proximity as occurs at operational airports. The objective was to achieve 97 percent probability of an ungarbled reply from one of two aircraft separated by 200 feet. The NAFEC tests proved that the GEOSCAN ® technique could meet this objective. This was achieved by generating an interrogation cell whose center was positioned within 20 feet of the target of interest at any range out to 1.5 nautical miles. The size of the cell was adjusted by controlling the antenna aperture size (16 or 6 elements) and the P_2/P_1 power ratio to provide for cell sizes ranging from 50 ft x 50 ft at 0.5 nautical mile to 600 ft x 600 ft at 1.2 nautical miles. By this means, the resolution capability indicated in Table 3 was achieved.

TABLE 3. MULTIPLE-TARGET RESOLUTION TEST SUMMARY

Test System	Range (Nautical Miles)	Separation (Feet)	Probability of Correct Reply (Percent)
NAFEC[a]	1.1	130	85
NAFEC[a]	0.85	150	95
NAFEC[a]	0.5	150	>99
Operational[b]	2.0	150	95

[a]Measured data.

[b]Predicted performance.

In addition to the two-target resolution tests, a number of other tests were run on targets to determine the reply probability versus the antenna-steering angle for various P_2/P_1 ratios. These tests substantiated that the desired resolution could be achieved.

5.4 UPDATE RATE

NAFEC test results showed that the 2-second update rate required by the contract could be furnished by the DAS. It should be remembered, however, that this has little meaning for brass-board operations because a preprogrammed scanning sequence was used, and interrogation of a target vehicle for tracking purposes was not within the capability of the DAS. Fruit and multipath did not limit the update rate even in the presence of three operating beacon interrogators (ASR-4, ASR-5, and ASR-7). Round reliabilities of greater than 90 percent were obtained at an update rate of 10 per second.

5.5 MULTIPATH

Vertical multipath in the ASTC surface environment would be manifested by fade loss without any troublesome distortion. This effect has been predicted by theory, and while it would limit coverage, it would cause no other significant problems.

Lateral or "out-of-beam" multipath, with its long time delays, is a potential problem in the surface environment. It could be controlled by providing adequate radiation pattern gain and a proper processing circuit design. Test results showed that the Bendix peak amplitude estimator (PAE) circuit, with its high multipath tolerance, successfully overcame the multipath signal levels encountered at NAFEC.

The TOA detection circuit performed as designed. Multipath signals at any amplitude with delays exceeding 100 nanoseconds had no effect on the TOA measurements. Likewise, the ID detection circuit functioned as designed when the multipath signals were 3 dB or more below the direct (desired) signal. Careful searches were made along the NAFEC runway/taxiway network within the DAS coverage region for severe multipath signals. Multipath signals affecting the DAS were detected by signal processing in the receiver PAE circuit since the sector omni (120 degrees) receiving antennas at all stations intercepted any and all multipath signals present.

In an operational system, multipath discrimination could be greatly enhanced by the simple addition of a sum-beam network to the phased-array antenna to form a narrow-beam pattern on receive. Also, as only one or two out of three valid ID's are required in a tracking system, software algorithms can be sued to reduce the probability of a false ID to an insignificantly small number.

Analysis of multipath sources that were found indicated that the multipath signal levels obtained at NAFEC would be typical of those in the runway/taxiway network at most airports. This conclusion is based on data from operations in the vicinity of the municipal terminal, the Air National Guard hangars, and the ATC Tower. Problems did occur with loss and garble of ID's at the Master and Slave Stations, but these were determined to be caused by a combination of digital and data-link circuit malfunctions and not by multipath. Results from multipath tests are summarized in Table 4 below.

TABLE 4. NAFEC MULTIPATH DATA SUMMARY

Multipath Amplitude (dB)	Signal Delay (μs)	Coverage Area Affected (percent)	Effect on TOA	Effect on ID
≥20 down	3	91	None	None
-9 to -20	1	8	None	None
-3 to -9	0.1	1	None	None
+3 to -3	0.2	0.01	None Meas-urable	Measured[b]

[a]Typical.

[b]Loss of ID at one of three sites during this condition.

From these test results, it is reasonable to expect that an ATCRBS trilateration system could overcome the effects of multipath, while maintaining accuracy, coverage, and update rate in any operational installation. Evaluation of limiting cases and the development of definitive quantitative measures of multipath performance with pattern-gain discrimination and software/hardware tracking capability require additional testing at typical operational airports as prescribed in the contract.

5.6 VEHICLE EFFECTS

Aircraft test results[6] indicated there was some azimuth shadowing or signal loss due to line-of-sight blockage by aircraft appendages, such as landing gear, flaps, etc. This signal-loss value was found to be approximately 15 dB maximum with nominal values of 5 to 7 dB for the DC-6, Gulfstream I, and Aero Commander aircrafts. These results agree with earlier Bendix tests on a 10:1 scale model B-707.

During DAS testing, a CV-580 aircraft was positioned at a point about 0.85 nautical mile from the Master Station and interrogator power set at the theoretical minimum triggering level (MTL) value for a nominal transponder at that range plus 7 dB additional

power for expected azimuth-shadowing effects. The aircraft was rotated in place, and round reliability greater than 90 percent was observed with a continuous update rate of about 4 samples per second during the complete turn. Vehicle effects did not interfere with the acquisition of continuous data from a Gulfstream aircraft taxiing down runway 4-22 or from a Cessna 172 taxiing along runway 8-26. Vehicle effects for wide-bodied aircraft (such as the B-747, L-1011, ect.) were not obtainable at NAFEC, and would require testing at airports where such aircraft normally operate. Test data, however, indicate that with such aircraft the effects of azimuth shadowing on accuracy, update rate, and coverage could be reduced by providing higher receive-pattern gain, and by adding redundant interrogation and receive sites.

5.7 RF INTERFERENCE

ATCRBS interference evaluation tests showed that operating the DAS at a PRF of 1520 caused no measurable degradation of ATCRBS performance.[a] This result was verified by observers and from the analysis of data extraction tapes from Philadelphia, Washington National, and NAFEC.[b] In addition, the DAS was synchronized with the NAFEC operational ASR-4. When the ASTC PRF was increased to 1520, the interrogation/suppression count in the NAFEC region almost reached the point where a statistical inference could be made of the effect on the ATCRBS round reliability by ASTC operations. Additional tests are required, however, to validate the theoretical prediction of the impact of the ASTC operations; it is expected that a DAS PRF of 2280 per second or higher would have to be used. TSC measurements of the ATCRBS surface environment at Logan (Boston) and at O'Hare (Chicago) airports showed that

[a]The projected operational PRF for O'Hare airport for 100 surface vehicles during peak hours with reinterrogations is approximately 1400.

[b]Observers in ARTC at Islip NY and Leesburg VA also reported no interference. NAS Stage A printouts corroborated these findings.

an ASTC DAS operating at the required operational PRF will not adversely affect ATCRBS systems in the region. Similar findings were developed at Los Angeles although some additional data must be gathered before a firm conclusion can be drawn there.

These tests tended to confirm results from previous TSC investigations which show that ASTC operations would not interfere with normal ATCRBS functions. For instance, transponders were activated in all moving aricraft on the surface during tests at Logan and O'Hare airports. This would be a requirement for an ASTC system. Results of these tests were favorable to operational ASTC system deployment. In addition, TSC measurements of the ATCRBS environment on the surface at Logan, O'Hare, and Los Angeles International airports support the contention that ASTC systems, operating at required PRF's, probably will not affect ATCRBS in those areas. Airborne ATCRBS environment tests, which TSC has scheduled for these airports, will lead to more conclusive assessments of the impact of an operational ASTC on ATCRBS.

The impact of ATCRBS on the DAS at NAFEC was minor. The NAFEC environment, with three operating ASR's, is severe from a fruit-generation standpoint. For this reason, DAS receiver sensitivity was reduced 10 dB. This would not have been necessary if the brassboard had a real-time computer to set independent range gates based on expected target range. In any case, round reliabilities greater than 85 percent were achieved consistently, and 90 percent or greater was typical of the measurements. For operational systems it should be noted that clear ID would not be needed at all three receivers, thereby reducing further fruit effects.

6. CONCLUSIONS AND RECOMMENDATIONS

The primary objective of Phase I of this contract, demonstration of technical feasibility of an ATCRBS based DAS, was successfully accomplished. Data acquired during the NAFEC field test series are in agreement with the results of earlier concept analytical studies. The technology required to support the concept is available, and functions as required. The following key technical points were established.

a. Trilateration accuracy was measured to be 37.8 feet, 3σ, well within the contract objective of 100 feet, 3σ.

b. Resolution was measured at a reply probability >97 percent for vehicles separated by 150 feet at a range of 0.5 nautical mile.

c. DAS coverage was measured to 1.13 nautical miles for aircraft with an antenna height of 3 feet. Interrogator power required at this range validates the theory for operational system coverage requirements.

d. Aircraft-target tracking (update rate) was confirmed over the available NAFEC test area up to 1.13 nautical miles maximum range, to a rate of 10 per second.

e. DAS performance was not adversely affected by multipath in the NAFEC test environment. This can be attributed to the multipath rejection capability of the brassboard system and the relatively clear ASTC multipath environment at NAFEC.

f. There was no problem with signal blockage and fading caused by vehicle effects for aircraft types available at NAFEC; i.e., Convair 580, DC-6, Gulfstream, and Cessna 172.

g. The brassboard was tested beyond projected operational PRF's without causing interference to local ASR systems either at NAFEC or at surrounding sites. These tests show that synchronization of the ASTC system with the local ASR may not be necessary for operational deployments.

h. The tests did not reveal any DAS system technical limitations or inherent shortcomings.

The brassboard DAS program is ready for Phase II testing in higher-density operational airport environments and some steps have already been initiated in this direction. These tests could not have been undertaken until NAFEC tests were completed because of concern relative to generating ATCRBS interference which might impact ATC operations. Results of NAFEC interference tests, however,

combined with environment measurements at Logan, O'Hare, and Los Angeles, show clearly that an operational ATCRBS trilateration system at these airports, operating at the projected PRF's, will not create measurable ATCRBS interference or ARTS III degradation. It is reasonable to conclude that the brassboard can be operated as necessary to acquire further test data to support ATCRBS trilateration operational potential and performance, without interfering with the present ATCRBS environment or adversely affecting airport operations.

Test planning and DAS hardware augmentation design for the Logan and O'Hare tests was exercised May 1975, see Appendix B.[9]

TSC is considering a hardware modification which will improve the ability of the brassboard in the area of real-time control and processing. The added capability is necessary at operational airports where the traffic density cannot be structured and controlled purely for test purposes. A DAS with real-time data presentation would allow data to be examined as they are taken, thereby permitting early detection and correction of system faults. A real-time tracking capability must be included to acquire preprocessed data in quantities necessary to evaluate the complex interrelationships among vehicle effects, multipath, resolution (a function of transponder characteristics), etc. Postprocessing all data in their new state is prohibitively expensive, requiring approximately one hour of machine processing time to reduce and analyze one minute of brassboard DAS data. More important, it severely limits evaluation of the contribution the system can make in aiding real operational situations.

Finally, now that technical feasibility is clearly established, it is appropriate to begin consideration of an operational sensor equipment configuration. This raises a host of new questions relative to such matters as increasing sensor capability (extended range and coverage, different modes of interrogation and measurement, beacon-system growth to DABS, etc.), interfaces with terminal ATC facilities, controller displays, surface automation applications (e.g., intersection control, runway occupancy estimation, etc.),

control algorithms and system architecture, and many others which have not been addressed to date. These questions need to be examined in the context of realizing a return in operational benefits from the investment made in this highly successful feasibility demonstration.

APPENDIX A

BRASSBOARD-EQUIPMENT AND TEST-DATA ILLUSTRATIONS

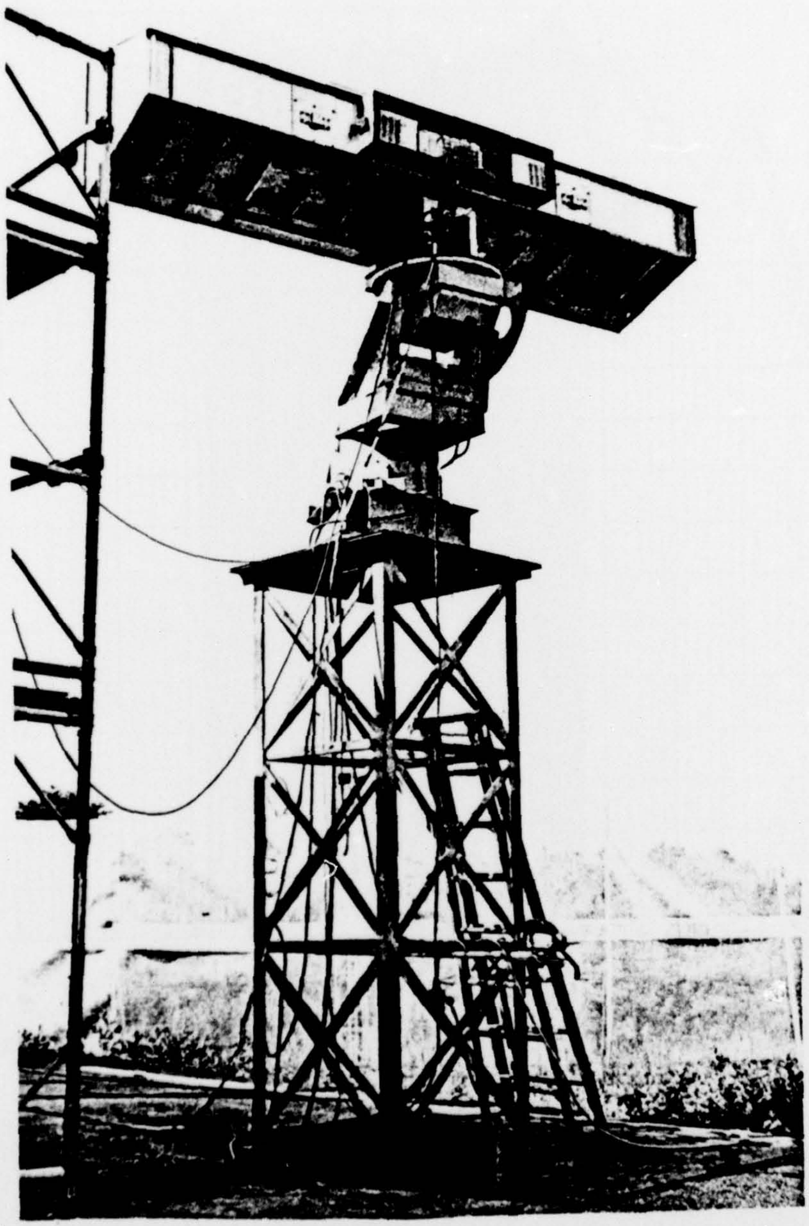


FIGURE A-1. PHASED-ARRAY ANTENNA DURING RANGE TESTING

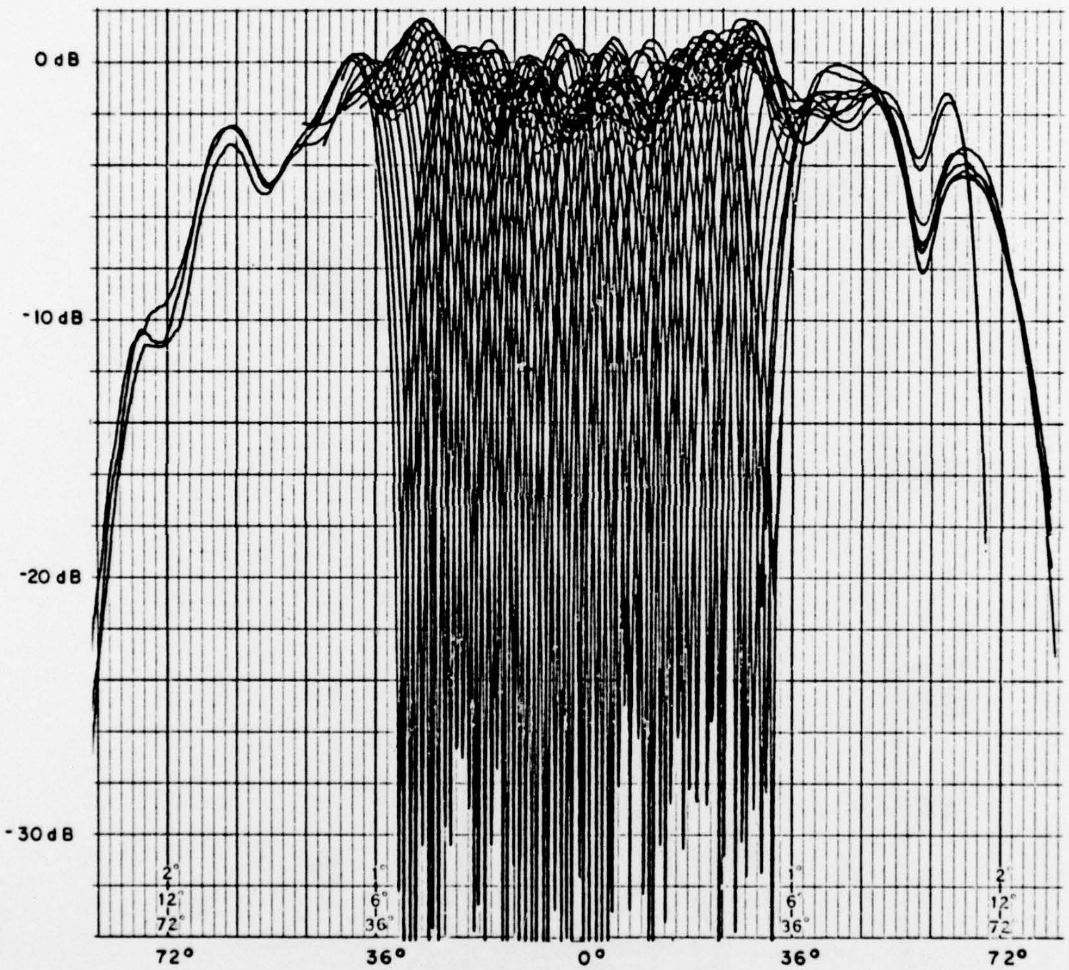


FIGURE A-2. BRASSBOARD DAS GEOSCAN® ARRAY ANTENNA TEST-RANGE DATA.

Measured at 1030 MHz with 1° steps across the full 64° coverage. Nulls greater than 25 dB obtained at all angles, not just the 1° increments plotted above.

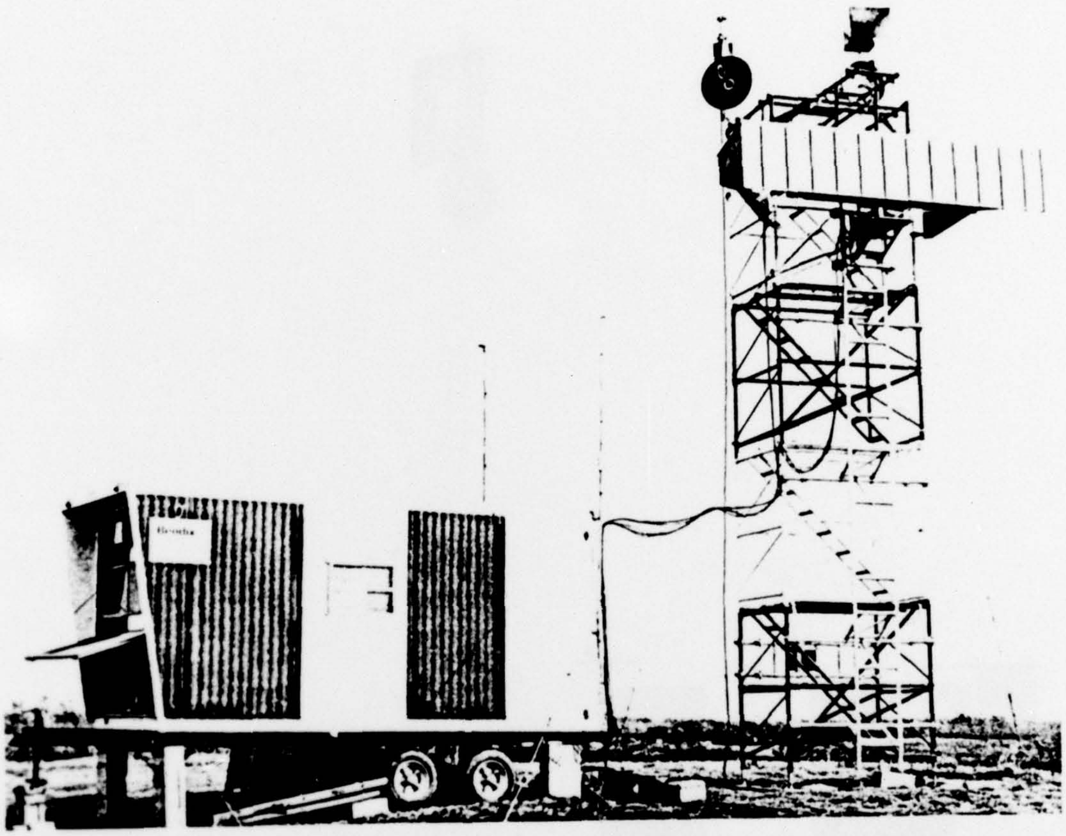


FIGURE A-3. BRASSBOARD DAS MASTER STATION INSTALLED AT NAFEC.

Equipment trailer with antenna tower. The tower supports the GEOSCAN^{R} phased array, the Master-Slave, and the Master-Receive site data-link dish antennas, and a horn antenna for receiving and synchronizing to the ASR Beacon Interrogator. The Slave Station is essentially identical except when it has only one data-link dish and no beacon synchronization receiving horn antenna.

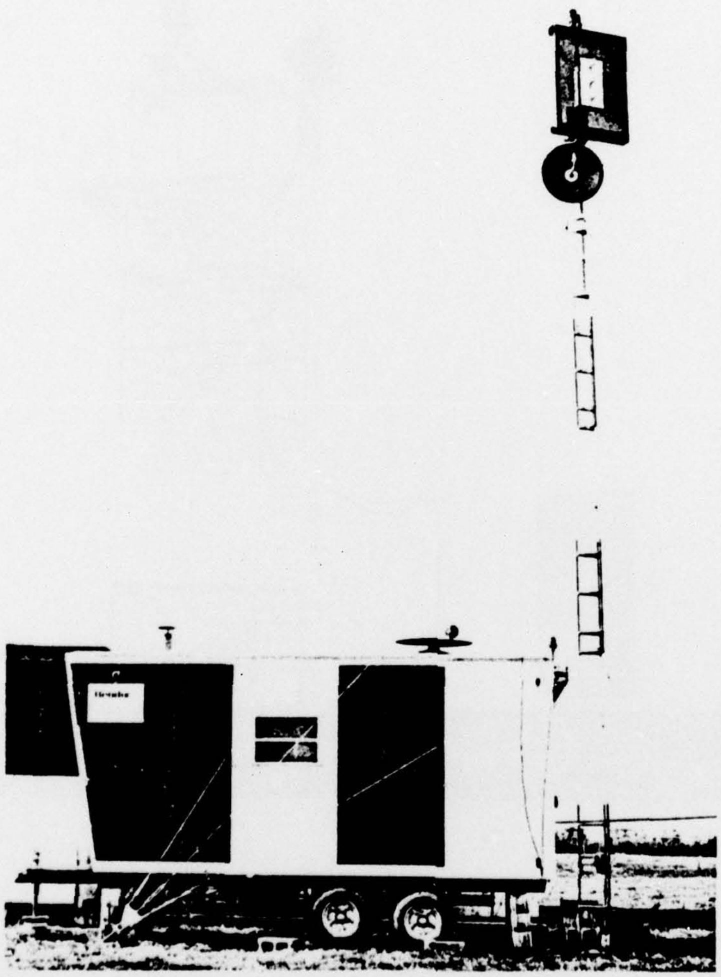


FIGURE A-4. BRASSBOARD DAS RECEIVE STATION INSTALLED AT NAFEC.

The equipment trailer houses the electronics equipment, while the trilateration receive-only antenna is mounted above the Receive-Master data-link dish on a crank-up triangular tower.

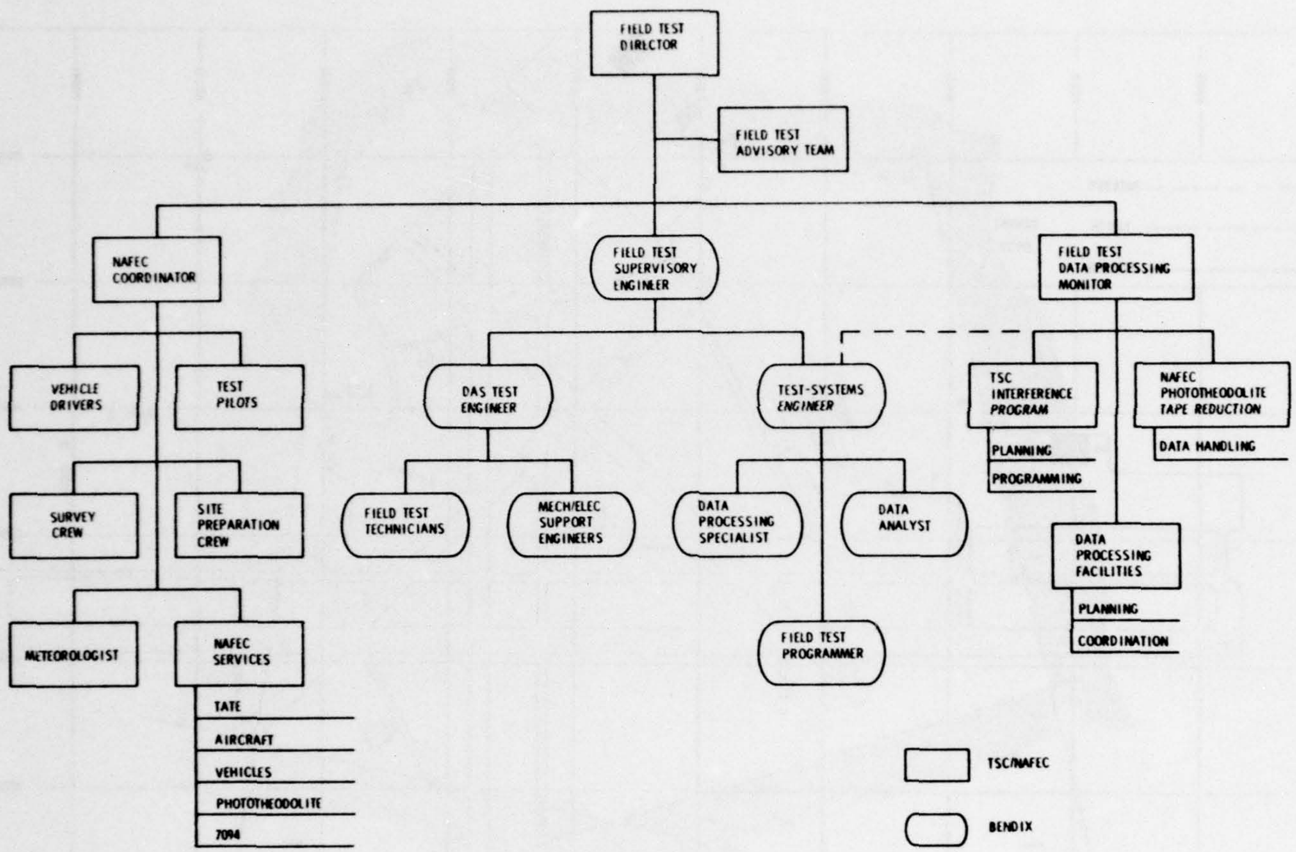


FIGURE A-5. ATCRBS TRILATERATION TEST TEAM

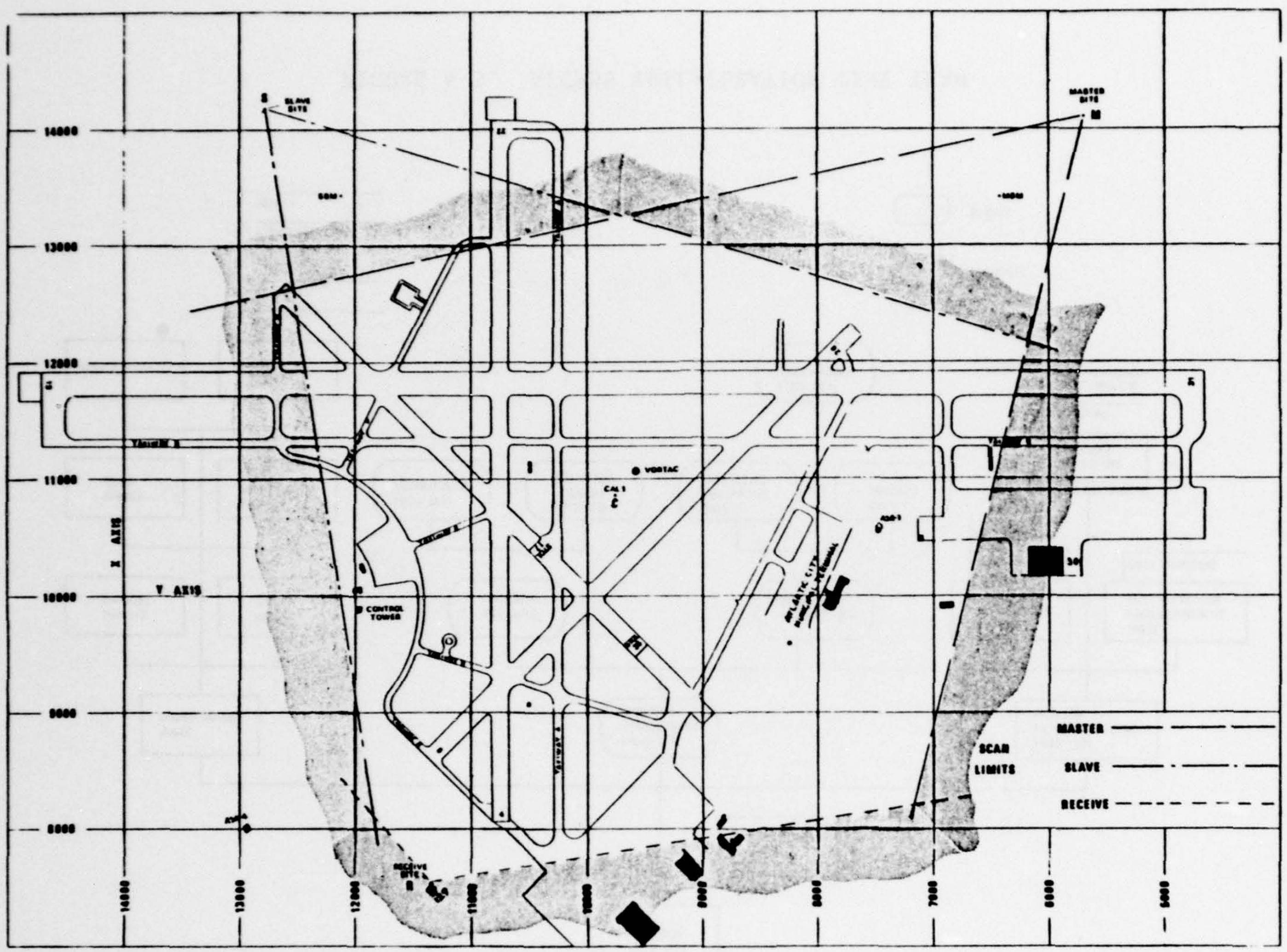


FIGURE A-6. BRASSBOARD DAS SITING AND COVERAGE AT NAFEC

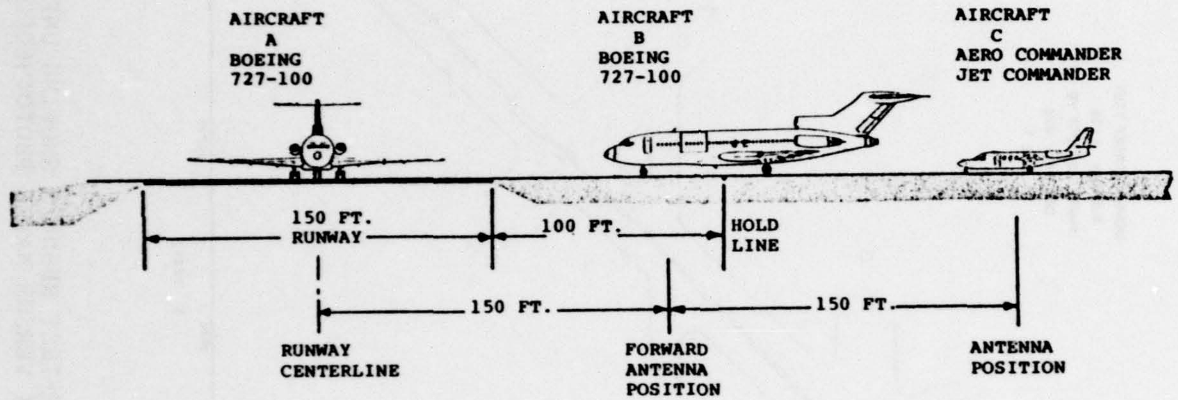


FIGURE A-7. SAMPLE RUNWAY/TAXIWAY INTERSECTION SITUATION.

The brassboard DAS can resolve each target and measure position to within 14 feet (1σ) with a round reliability greater than 95%. In this case, aircraft B has violated the holdline by 50 feet, and the ASTC system would have detected it.

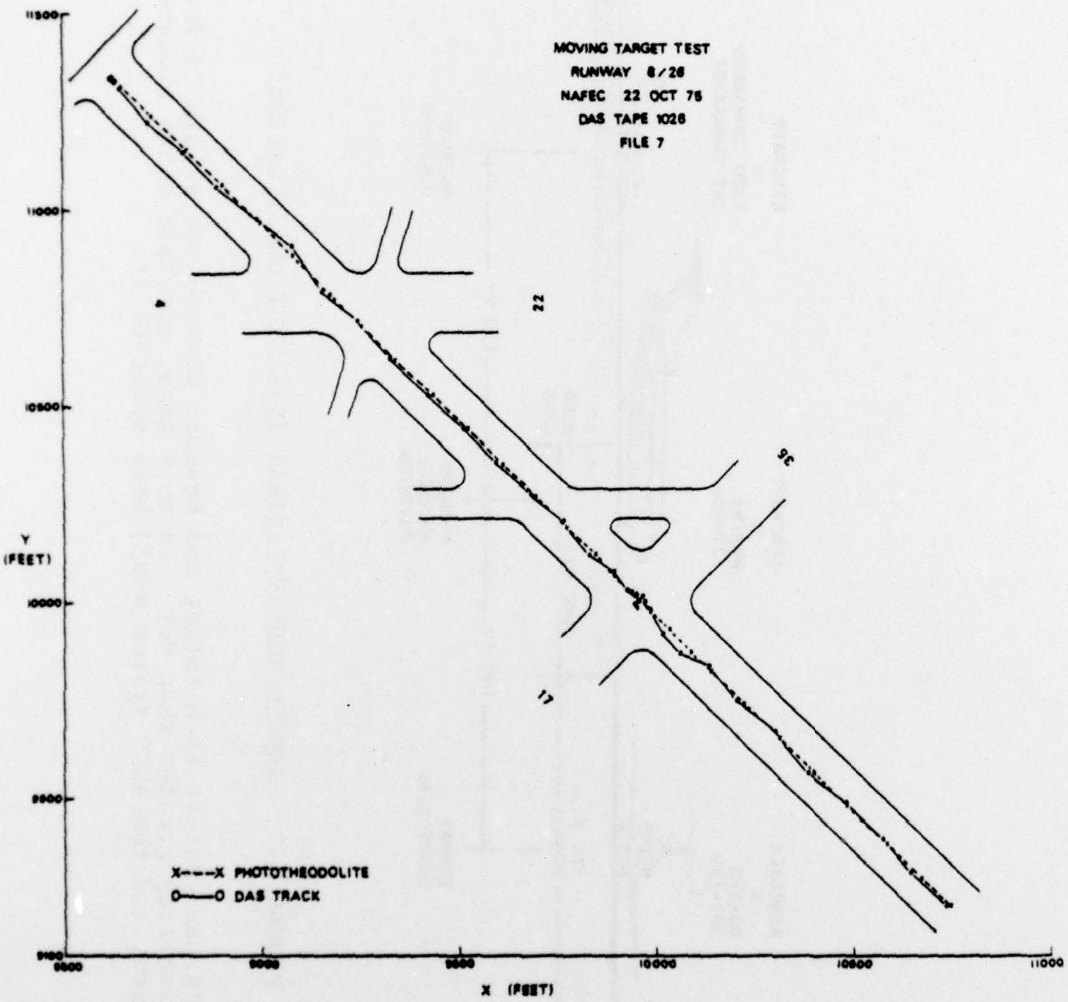


FIGURE A-8. NAFEC TEST RESULTS SHOWING UNFILTERED, UN-SMOOTHED DAS TRACK VERSUS NAFEC PHOTOTHEODOLITE TRACK.

Vehicle stopped on centerline of runway 17/35 during the tracking run.

APPENDIX B
SUMMARY OF WORK ACCOMPLISHED UNDER CONTRACT OPTION 1

Contract Option 1 for Logan and O'Hare test planning and DAS hardware augmentation design was exercised on 15 May 1975. In addition to preparing field-test plans, a design study was conducted to determine the most effective manner of augmenting the DAS with a capability for real-time performance evaluation. The modified DAS would provide semiautomatic tracking of a limited number of surface targets, and eliminate the manual control and programming used during NAFEC testing. The phased array antennas would be modified to provide greater resolution at maximum range. Most important under the proposed augmentation would be real-time engineering display. This display would be operated in parallel with the recording of data on magnetic tape for off-line computer processing. These changes would be amenable to future upgrading of the DAS without redesign of existing hardware to provide fully automatic operation.

An application for temporary operation of the brassboard DAS at Logan was submitted, and has been approved by the FAA. This application included proposed DAS site locations, obstruction clearances, and an evaluation of radio/radar navigation and communication interference. Preliminary meetings with Massachusetts Port Authority representatives have been held, and the Logan installation can proceed as funds for Option 2 are made available.

APPENDIX C

REFERENCES

1. Trilateration Data Acquisition Subsystem (DAS) Analysis and Test Outline Report, Interim Report, Bendix Communications Division Report 489A01, 1 August 1974; on file at the TSC Library.

2. Task 1A Critical Issues Working Paper, Interim Report, Bendix Communications Division Report 489A02, Revision A, 6 March 1975; on file at the TSC Library.

3. A Beacon Trilateration Data Acquisition Subsystem: Interim Design Report, Bendix Communications Division Report 489A04, Revision A, 28 February 1975; on file at the TSC Library.

4. U.S. Department of Transportation, Federal Aviation Administration Order 1010.51A, U.S. National Aviation Standard for the Mark X (SIF) Air Traffic Control Radar Beacon System (ATCRBS) Characteristics, 8 March 1971; on file at the TSC Library.

5. F.D'Alessandro et al., Airport Surface Traffic Control Concept Formulation Study (4 Vols.), Report No. DOT-TSC-FAA-75-8; FAA-RD-75-120, July 1975.

6. J.D. Vinatieri, Experimental Measurements of Beacon Antenna Radiation Patterns for Surface Aircraft, Test Report, MITRE Corporation Report MTR-2780, 26 February 1974.

7. ATCRBS Surface Interrogation and Interference Measurement Program (Measurement at Logan Airport), Test Report, MITRE Corporation Report MTR-2736; Vol. I, 12 December 1973; Vol. II, 28 March 1974.

8. M.J. Moroney and H.J. Glynn, Measurement of ATCRBS Surface Interrogation Environments at Chicago O'Hare and Los Angeles International Airports,Report No. DOT-TSC-FAA-76-17; FAA-RD-76-176 July 1976.

9. Report of Work Performed Under Option 1 of Contract DOT-TSC-769, Final Report, Bendix Communications Division Report 489A06, October 1975; on file at the TSC Library.

APPENDIX D
REPORT OF INVENTIONS

Although no inventions, discoveries or innovations were made under this contract, the brassboard model air traffic control radar beacon system (ATCRBS) sensor developed and tested under this contract did successfully demonstrate the feasibility of an improved, previously developed beacon-based approach to airport surface traffic control (ASTC). Test data showed that the accuracy of the multilateration receiving system and the resolution of the spatial interrogation technique combined favorably to equal or exceed ASTC requirements delineated by the Transportation Systems Center. Additional technical factors such as surface coverage, multipath and vehicle shadowing also were addressed and the ability of this new technique to control their effects while meeting ASTC performance requirements was established. Most importantly, several tests were conducted which showed that this improved ATCRBS trilateration surface system will blend in with existing and planned air traffic control systems.

This system portends significant improvements over the state-of-the-art surface traffic surveillance methods. This is the first technique which can automatically provide aircraft identity as well as position location to ground traffic controllers. Furthermore, no other surface system can provide this information with the immunity to weather conditions offered by ATCRBS trilateration.

Although this contract was concerned specifically with the sensor portion of a surface traffic control system, it is clear from the data gathered in the test series that the operational deployment potential of an ATCRBS based system is extremely high.

190 copies